Coherence of Sound using Navy Sonars: Deep Water Acoustics

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LONG-TERM GOALS

The long term goals are to 1) determine when methods can be used to reliably and accurately predict the temporal and spatial coherence of sound at low frequencies in the sea, 2) develop reliable and accurate methods to make such predictions and, 3) determine the physical mechanisms affecting coherence. The first two goals are to be achieved without tuning with data in any way whatsoever.

OBJECTIVES

The primary objective is to determine when the temporal and spatial scales of coherence are accurately predicted by solving an approximation of the acoustic wave equation for climatological conditions in the ocean perturbed by a time-evolving field of internal gravity waves following a standard spectrum. These waves have long been thought responsible for coherence in the deep ocean at low frequencies. Despite decades of theoretical work to predict coherence, theoretical models to date are highly unreliable, often being inaccurate by several orders of magnitude. We are comparing numerical predictions for coherence with data collected with Navy sonars.

A secondary objective is to understand how to quantify the regions of the ocean that influence acoustic signals that are measured at a receiver. The classic picture of such regions is described by ray paths, which are solutions of the wave equation at high frequency. Modern theories of diffraction have the ability to quantify the regions exactly for any finite frequency and bandwidth (Spiesberger, 2011b). Since the exact regions that influence sound look very different than where rays propagate at low frequency, it may turn out in the long-term that the modern theory will replace the use of rays for many applications in basic research and surveillance.

APPROACH

To pin down whether the problems for predicting coherence time were due to the theories or the ascribed physical mechanism of internal waves, we began eight years ago a numerical set of computations of the acoustic field with standard models at time intervals matching measurements (Spiesberger et al, 2003). These computations have the advantage of not using any theoretical support from scattering theories. This allows a strong test for the hypothesis that internal gravity waves determine coherence at low frequencies in the sea. The sound speed field for the numerical model is

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synthesized by adding sound speed perturbations due to internal waves to a climatological background of speed. The linear dispersion relation is used to temporally evolve a standard spectrum of internal waves. For each snapshot of sound speed along a section, the split-step sound-speed insensitive parabolic approximation (Tappert *et al*., 1995) is solved on a computer for the frequencies used for each acoustic transmission. The temporal response is computed using the inverse Fourier transform. The predicted acoustic field at the receiver is saved. This collection is analyzed in exactly the same manner as the data, including setting the signal-to-noise ratio from the model to be the same as for each measured acoustic reception.

WORK COMPLETED

We finished analyses of sections of length 1346 km and 3709 km in the Pacific from our global acoustic warming experiment that began in 1983 (Oreskes, 2004). The 1983 component of these data are particularly useful measurements because they consist of continuous transmissions at two-minute intervals lasting five days. The source and receivers are mounted on the seafloor with time bases controlled by atomic clocks. The ocean is the only thing that affects the acoustic measurements, as there are no aberrations from instrument motion.

RESULTS

Section F in Figure 1 is a 1346 km section from transmissions in 1986-7 centered at 133 Hz and a temporal resolution of 0.06 s. It is one of six experiments analyzed to date where temporal measurements of coherence have been compared with numerical computations without tuning with data. Four of the other sections yielded excellent resemblance between observations and models. In one section (E), the comparison yielded no conclusion because the data were not analyzed correctly for this application (Spiesberger , 2006).

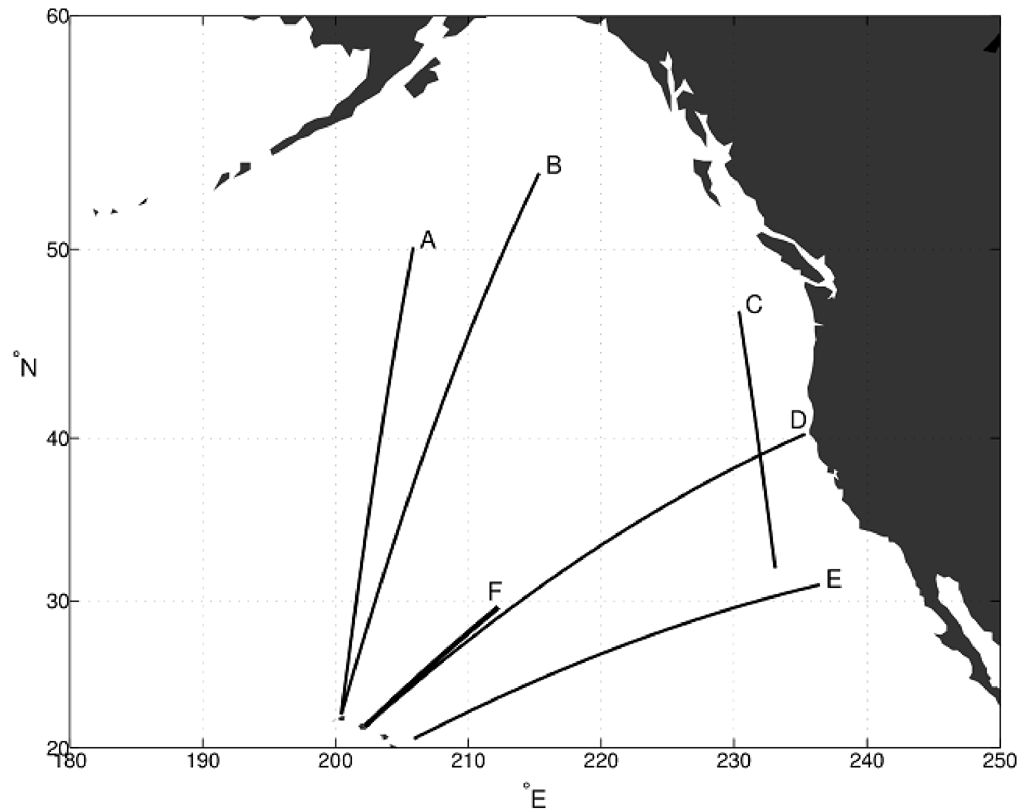

Figure 1: Six sections where the temporal coherence of sound has been compared with models without tuning with data.

The current comparison with data (Figure 2) shows the probability distribution of coherence time. Coherence time is defined to be the duration of a coherently integrated acoustic signal yielding maximum signal-to-noise ratio at the receiver. The most important result is that the model yields a very accurate prediction for coherence time without tuning with data. The comparison indicates that it is unnecessary to invoke physical mechanisms beyond internal waves to explain temporal coherence in this experiment.

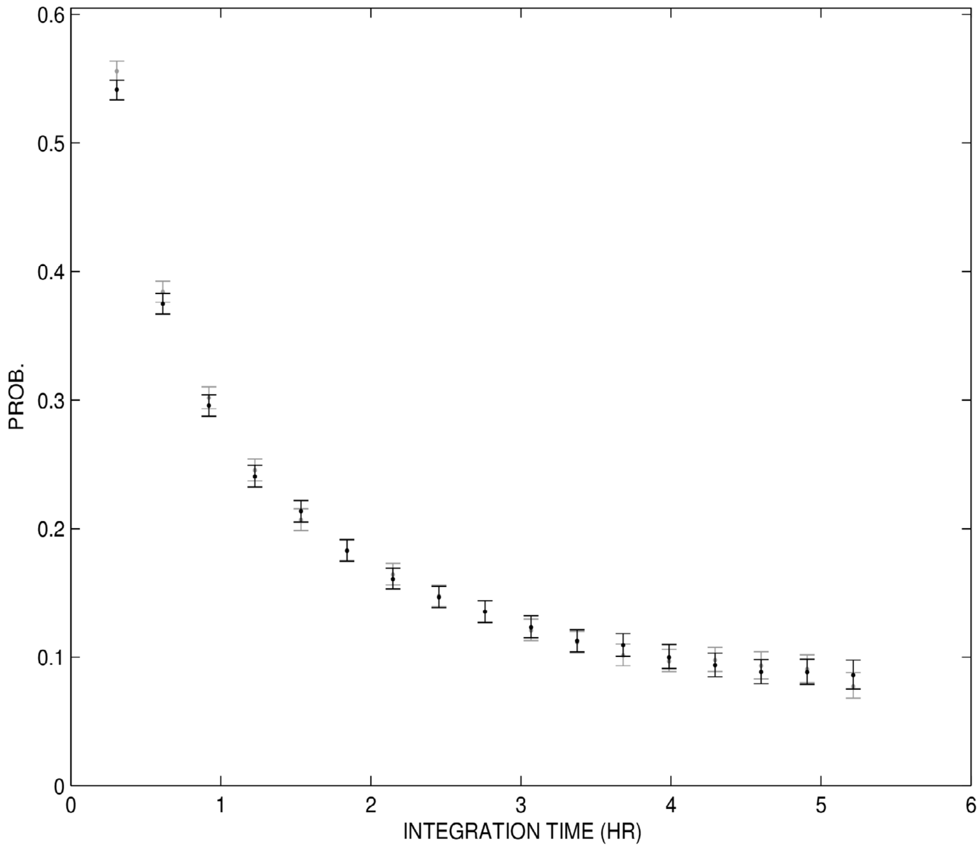

Figure 2: Coherent integration time of data (dark) and model (light gray) with 95% confidence limits for section F in Figure 1.

IMPACT/APPLICATIONS

Accurate computations and predictions for temporal coherence have applicability to surveillance, theoretical work in scattering theory, design of acoustic experiments, and underwater acoustic communication systems. Understanding temporal coherence of sound has been one of the most important issues for anti-submarine warfare since WWII.

RELATED PROJECTS

Because of the importance of acoustical coherence both theoretically and practically, many scientists study the coherence of sound. These include Drs. Buckingham, Worcester, Vera, Godin, Voronovich, Colosi, Morozov, Orr, Rouseff, Kuperman, and Duda. Many others not listed here have or are making important contributions.

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